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178

# WALL PICTURES

TO ILLUSTRATE

# THE MINUTE STRUCTURE OF PLANTS

MAJOR F. BAILEY, the Director of the Indian Forest School, some time ago suggested to me to send to Dehra Dún a collection of large-sized illustrations to be used in the Botanical teaching at the Forest School. This suggestion I discussed with Dr. Edward Strasburger, the Professor of Botany in Bonn University, and he has kindly made a selection for me from the illustrations which he uses in his lectures, and has, moreover, superintended the copying of them. Some of the illustrations are taken from the published works of other authors; the majority, however, are enlarged copies of drawings made by Professor Strasburger himself, some published, some as yet unpublished. Ten plates have been taken entirely, and a few more partially, from the work "Wandtafeln für den Naturwissenschafftlichen Unterricht Pflanzenkunde" by Kuy.* In some of these important corrections have been introduced.

The numerous discoveries made by Professor Strasburger in anatomical and physiological Botany, as well as his excellent work "Das Botanische Practicum, Jena, 1884," are probably known to Botanists in India. For the information of the students at Dehra Dún, I may add that he is now one of the leading authorities in this branch of Botanical Science. An English translation of an abridged edition of his "Botanisches Practicum" is expected to appear ere long.

While I am indebted to Professor Strasburger for the selection of the illustrations, I am alone responsible for the explanations. In framing these explanations in English, I have to a great extent used the terms employed in George Lincoln Goodall's "Physiological Botany" (second volume of Asa Gray's "Botanical Text-Book"), New York and Chicago, 1885, and in Bow and Scott's translation of A. de Bary's "Comparative Anatomy," Oxford, 1884.

* Abbreviated in the notes.—Kny Wandt.

III
178
5628
178

The illustrations represent the more important points relating to the histology of phænogamous plants. The teacher should consult several plates for the representation of one object. Thus he will find the protoplasm and cell-nucleus represented on plates 2, 3, 5, 6, 8, 11, 24; starch grains on plates 4, 5, 21; intercellular spaces on plates 1, 5, 22, 25, 26; and ducts on plates 9, 14 to 19, 21, 22, and 28.

To the list of plates I have added a few notes in order to draw attention to some important points. I have also given references to the best recent works upon the subjects illustrated by the plates. I could not have undertaken to enter into anything like a complete explanation of the plates. This would have assumed the shape of a book.

I have read with the greatest satisfaction the periodical accounts of the progress made in the Forest School, which have appeared in the *Indian Forester* and elsewhere, and I was pleased to see that, in the first year's theoretical instruction, Vegetable Physiology, including the structure of wood, occupies the first place. In undertaking the present work, my wish was to facilitate the teaching of this subject. The time allotted to the course of theoretical instruction at the Forest School is necessarily short, the science of anatomy and physiology of plants is exceedingly large, and the indefatigable researches of numerous workers in Germany, France, and Great Britain, as well as in other countries of Europe and America, are developing and enriching it steadily. Hence in organizing the teaching at an institution like the Forest School at Dehra Dún, the aim should be to make a good selection of subjects. Unless this is done in a methodical manner, no satisfactory results can be attained.

Hence, in the present work, I have confined myself almost entirely to phænogamous plants, and my sole aim has been to facilitate a good understanding by teachers and students of a few leading points. *First*, the different descriptions of cells and their arrangement in tissues—epidermis, parenchyma, and fibro-vascular bundles. *Secondly*, the arrangement of tissues in roots, stems, and leaves. *Thirdly*, the chief organic substances which are necessary for the life of these plants.

I wish to seize this opportunity to state my opinion strongly that the students at the Forest School will not be able to grasp the leading facts of anatomy and physiology of plants without a good knowledge of some portions of organic Chemistry and of systematic Botany. Further, that

Chemistry, in order to be fully understood, must be practised by the students in the Laboratory, and that the teaching of systematic Botany must aim at giving them a good practical knowledge of the trees and shrubs of which the forests are composed. Here, again, a good selection of subjects is essential. Such a selection is practicable, and upon the greater or less skill with which this selection of essential points is made, the greater or less success of the teaching at Dehra Dún will depend.

The present work is restricted to a few of the most elementary and most important matters in regard to the anatomy of plants, and yet at every step almost we stumble upon questions not yet finally settled and matters not yet cleared up. In my notes I have made a point of drawing attention to a few of these doubtful points. And yet the matters to which the present work relates have been the subject of research and experiment by a large number of eminent Botanists during the present century. In most cases, the plants of Europe with which these Botanists were perfectly familiar have furnished the material for these researches. New and unexpected discoveries are being made constantly at the present time. I have no greater wish in connection with this work than that the plates and the suggestions which I have thrown out in my notes may induce some of the professors and students at the Forest School, and Foresters in India generally, to commence independent researches on botanical questions with or without the microscope.

How much may be done to correct errors and to make discoveries, even in those matters which are believed to be firmly established, is shown by the excellent work done by some of my former colleagues in India, in order to determine with certainty the time required to ripen the seeds of the Deodar and *Pinus longifolia*, and to correct the errors into which I had fallen when writing the "Forest Flora of North-West and Central India." The plates of the present work and my notes may contain many imperfections, and it will be a satisfaction to me to learn that an improved edition has been prepared by Indian Foresters. In an Indian edition, the material ought to be taken from Indian trees and plants.

To my mind, the most satisfactory feature in the Dehra Dún Forest School is that it has been established and is maintained for the Natives of India. Through the influence of this institution mainly, we must hope that Forestry

in India will become naturalized, and will cease to be an exotic plant. When the organization of Forest Ranges has been completed, there will be more than 1,000, perhaps more than 1,500, Forest Rangers in all India, and the Forest School will thus exercise its influence on a large scale, and perhaps several such institutions will then be formed. The teaching of practical professions, which are based upon science, and which are connected with the land, like Agriculture and Forestry, is, I feel assured, destined to accomplish great things for the welfare of the people of India.

Wall-pictures are often mounted upon cardboard to hang up. The arrangement adopted by me is, I believe, preferable in the present case. They are fastened with drawing-pins upon a blackboard, or wherever they may be wanted.

BONN,
*May 1886.*

D. BRANDIS.

# LIST OF PLATES.

*I.—Different kinds of Cells; their contents and development.*

1. *Different kinds of parenchyma.—Note* pits in the walls of cells of *Yucca.*

2. *Protoplasm currents and cell division.—Note* the circulation of protoplasm in the hair of *Cucurbita.* The currents form a network of threads, in which is embedded a large nucleus.

3. *Nucleus and protoplasm currents.*—I. *Elodea canadensis,* also called *Anacharis Alsinastrum,* is a remarkable waterplant, originally indigenous in North America, where it is common in slow streams and ponds, but not troublesome. Accidentally introduced into Great Britain in 1836, where it became exceedingly troublesome by its rapid increase, blocking up navigable waters, hence known as the "Waterpest." The cells of the leaves of this plant show the network of protoplasm currents, similar to that of *Cucurbita* (plate 2), in which are embedded nuclei and chlorophyll grains. *II. Tradescantia:* piece of one of the long violet stamen hairs. Here, as in *Cucurbita* and *Elodea,* the threads of the protoplasm network carry numerous minute granules (microsomata), and it is by means of their locomotion that the circulation can be seen. The movement takes place in different directions, and sometimes the granules of one thread move in opposite directions. The nucleus forms, as it were, the centre of the network, and it also shows a movement, but very slight and slow. A clear lilac sap fills the rest of the cell. (Compare page 47, fig. 21, of Strasburger's "Botanisches Practicum," German edition.) The network of circulating protoplasm currents is also shown on plate 11, in the hairs of the madder and the stinging nettle. Protoplasm is, so to say, the living matter of the plant. In the living tissue it probably is in constant movement, passing from one cell into another through the openings and their portions (pits) of the cell wall. In hairs and the tissue of some water-plants, such as *Elodea,* its circulation is most easily seen under the microscope; but, with skilful treatment, the circulation can also be distinguished in other living tissue—*e.g.*, in medullary rays of the sapwood.

4. *Starch granules* (Kuy Wandt.) *and starch generators.*—Starch is the most important vegetable non-nitro-

genous substance which is stored in cells for future use. *Note* simple and compound grains and their stratification. Protoplasm is the origin of starch, as of most other vegetable substances, and the protoplasmatic bodies from which the starch grains develop are called starchgenerators. The are often green (chlorophyll), and starch grains are frequent in the interior of chlorophyll grains.

5. *Protein granules.*—The principal nitrogenous (albuminous) substance which is stored in the endosperm, or cotyledons of seeds, for future use is generally called Protein. Where it occurs associated with starch, as in the cotyledon cells of the Pea, it consists of numerous small granules. These small protein granules of the Pea have a compound structure, which it would be out of place here to explain. Peas contain 2 to 3 per cent. of their weight of fat; most of it is in the cells of the radicle, but some in those of the cotyledons. It is probable that this fat is mixed up with nitrogenous matters in the protein granules. A very thin section is represented on the plate. To the same class of seeds as the Pea, in which starch is the chief non-nitrogenous stored substance, belong Wheat and Barley; but here the starch is stored in the endosperm.

Another class of seeds are those which contain fat as the chief non-nitrogenous stored substance. Thus fat or oil fills the cells of the embryo in rapeseed, *Sesamum* (*til*), hemp, and of the endosperm in *Ricinus* (castor-oil), the cocoanut, and linseed. The protein substances which are associated with fatty stored matter present certain important peculiarities in appearance and chemical reaction, and have, therefore, by some authors been called aleurone. They frequently contain conglomerations of double salts of calcium and magnesium, with phosphoric acid and an organic acid, called globoids, as well as crystals of calcium oxalate; and a portion of these nitrogenous substances is often crystallized (protein crystals or crystalloids). In the present case, it will be convenient to use the term aleurone for the peculiar class of protein substances represented upon this plate. One of its peculiarities is that it dissolves more or less readily in water; hence it is convenient to examine sections of these seeds in glycerine or in oil. The left hand figures on the plate represent cells of the castor-oil endosperm. In concentrated glycerine large aleurone masses are seen, with a few globoids and drops of oil which have become separated from the protein. On adding water, the

appearance of the cell contents changes, protein crystals are seen, as well as globoids. These are seen more clearly in heated glycerine.

A third class of seeds are those in which the non-nitrogenous stored substance is neither starch nor oil. In the seeds of the Date Palm, the cells of the endosperm are filled with cellulose, which is converted into a soluble carbo-hydrate at the time of germination, in the same manner as is the case with starch and oil in the seeds already mentioned. Matters are different in the seeds of the Lupine. The cotyledons of the numerous species of the genus *Lupinus* contain no starch, and only a small quantity of oil. The seeds of the yellow Lupine (*Lupinus luteus*) contain 5% fat, 29% of non-nitrogenous substances, 14% cellulose (walls of the cells), and 35% protein substances. *Lupinus polyphyllus* contains more fat (14%) and more protein (44%). The plate represents a cell from a seed not quite mature, which shows the cell-nucleus and, in addition to the large masses of aleurone, small grains of incipient or nascent chlorophyll. This is of *Lupinus polyphyllus*. Of *Lupinus luteus*, a cell is figured immured in olive-oil: it shows the large masses of aleurone and a crystal of calcium oxalate. It would lead too far here to discuss the nature of the non-nitrogenous stored substances in *Lupinus*. Suffice it to say that the protein substances here are similar to those in seeds, in which the chief stored non-nitrogenous substance is oil.*

The subject of aleurone has not yet been fully cleared up. The most comprehensive treatise is Pfeffer, Protius Körnor, Pringsheim Jahrl f. Wissenschaftliche Botanik, VIII, page 429. See also Strasburger's Bot. Pract., page 41, and Sachs Botanik, 2nd edition, page 51; Sachs "Vorlesungen über Pflanzenphysiologie," 1882, page 403.

6. *Crystals of calcium oxalate* (Kuy Wandt.).—Regarding the great physiological importance of this substance, crystals of which are so common in plant cells, see Sachs' Vorlesungen, page 393.

7. *Colours of flowers* (from Hildebrand in Pringsheim Jahrlectur für Wissenschaftliche Botanik, 1863, Vol. III, page 59).—The blue, violet, rose, and red colours of flowers are mostly, but not always, caused by the cell-sap having that colour. The blue inner petals of *Strelitzia* have blue

* For microscopic structure and chemical composition of seeds, see Harz, "Landwirthschaffliche Samenkunde," vol, 1, 2 Berlin, 1885, Lupinus II, page 586.

granules, and so has *Tillandria*. Orange and yellow are generally caused by granules; those of *Strelitzia* (outer petals) are spindle-shaped, often twisted, and forming rings. The yellow stamens of *Acacia dealbata* (Silver Wattle) have their cells partly filled with a thick yellow fluid.

The dark brown of the corolla of *Scopolia* is caused by a blue sap and yellow granules in the outer, and yellow granules in the inner, layers of cells.

The red colour of *Euphorbia fulgens* is caused by a layer of cells with pink, and another with yellow, sap.

The deep orange of *Canna* is caused by alternating layers of cells with pink sap and yellow granules, and with yellow granules only, while the yellow portion of the petal is caused by yellow granules in a colourless sap. The orange-red colour of *Eccremocarpus* is caused by a similar arrangement, the yellow granules being most irregular in shape.

8. *Changes of nucleus during cell division, according to Strasburger's latest discoveries.*—When the nucleus begins to grow, the nucleoli disappear and it is transformed into a spindle-shaped mass, the equator of which is occupied by the nucleolar disc. This splits into two portions, developing into two separate nuclei, and midway between them a plane of minute granules is formed, which is the beginning of the wall between the two new cells. A wall of cellulose is formed out of the protoplasm, which, therefore, must be supposed to contain carbo-hydrates as well as nitrogenous matters.

9. *Elements of wood and bast (xylem and phloem), isolated by maceration with potassic chlorate and nitric acid* (Strasburger "Botanisches" Practicum," page 159).—The distinction between tracheides (D., E.) and ducts vessels (I., F.) is that the transverse partition walls of ducts are perforated; but it is doubtful whether this distinction ought to be maintained.

10. *Sieve tubes* (Strasburger's Bot. Pract., pages 147, 149, 166.)—They are long thin-walled cells with soft membranes, with sieve plates at the ends, and often also at the sides. The sieve plates are dotted panels, the dots perforated when old. They are found associated with bast fibres in the bast portion (phloem) of fibro-vascular bundles of dicotyledons and gymnosperms. They are also known as cribrose cells and cribriform tissue. When young, the walls are lined with a delicate film of protoplasm and a layer of

albuminous substance. A thick mass of this albuminous substance, called callus, is found on the sieve plates of young sieve tubes. Sulphuric acid causes the albuminous substance to contract. Sieve tubes are always accompanied by elongated companion cells, filled with protoplasm and containing nuclei. It is probable that sieve tubes play an important part in the formation of albuminous substances in the plant.

### *II.—Epidermis.*

11. *Hairs of plants* (Kuy Wandt.).—Those here represented are all simple hairs, consisting of one cell only, being the prolongation of a single epidermal cell, supported in *Rubia* and *Urtica* by a protuberance of the epidermis. There are also compound hairs, consisting of several cells, which start from a single epidermis cell or from a group of such cells.

The network of protoplasmatic currents has already been mentioned (see plate 3).

12. *Stomata on leaf of Thymus Serpyllum* (Kuy Wandt.).—*Note* the thickened outer wall of the epidermis, and the thickening of the guard cells; also the absence of chlorophyll in the other epidermic cells.

13. *Multiple epidermis and cystolith* (Kuy Wandt.).—The shining leathery hairs of the caoutchouc tree of Assam and Burma (*Ficus elastica*) have a multiple epidermis, distinguished by the absence of chlorophyll in the cells. Some of the cells of the innermost epidermis layer increase in size, and into these protrudes a mass of cellulose incrustated with calcium carbonate. Upon the application of dilute hydrochloric acid bubbles of carbonic acid are seen, and a delicate cellulose skeleton remains. The hardness of mature bamboos is caused by the incrustation and impregnation of the cell walls with silica in a similar manner. (See De Bary's Anatomy, English translation, page 104; Strasburger's Bot. Pract., page 230.)

### *III.—Fibro-vascular bundles.*

14. *Transverse section of fibro-vascular bundle of the Sugarcane* (Kuy Wandt.).

15. *Longitudinal section of fibro-vascular bundle of Maize.* (Strasburger's "Bot. Pract.," page 115.)

These two plates represent the fibro-vascular bundle of monocotyledons. It is surrounded by the bundle-sheath, consisting of several layers of thick-walled elongated cells with oblique pits, surrounded by parenchyma. The xylem or wood portion is towards the middle of the stem, and contains

annular, spirally thickened, and pitted ducts. The phloem or bast portion contains sieve tubes and companion cells.

16. *Transverse section of fibro-vascular bundle in the runner of Ranunculus repens* (Strasburger's Bot. Pract., page 131).—A number of bundles are arranged in a circle, and they are surrounded by parenchyma. In general appearance the bundle is similar to that represented on plate 14. On the inner face, towards the centre of the stem, there is the wood portion (xylem), formed of spiral ducts and ring ducts inside, and pitted ducts in the middle part of the bundle, the ducts being accompanied by wood parenchyma cells. Between this portion and the sieve portion of the bundle, there are several layers of radially arranged thin-walled cells. These are cambium cells, and they are wanting in the bundles of monocotyledons. Outside the cambium, there are sieve tubes with smaller companion cells, the latter being readily recognized by their protoplasmatic contents. In the place of the continuous sheath of monocotyledons, there is an inner and an outer layer of elongated sclerenchymatic cells, those on the outside having very thick walls.

Fibro-vascular bundles, which, like the present and like those of monocotyledons, have side by side a single strand of wood and of bast or liber—in other words, a single strand of xylem and of phloem—are called collateral bundles.

17. *Transverse section of fibro-vascular bundle; young shoot of Cucurbita Pepo* (Kuy Wandt.).—This is a bicollateral bundle—that is, a strand of liber is on each side of the wood portion. Spiral and ring ducts, with two very large pitted ducts, occupy the centre of the bundle, together with wood parenchyma. Outside of the wood portion of the bundle are several layers of radially arranged cambium cells. Both inside and outside, there are strands of liber, consisting of sieve tubes and companion cells. Four sieve plates are visible, showing what plate 10 represents on a large scale. There is no sheath whatsoever of thick-walled cells to separate the bundle from the parenchyma.

18. *Transverse section through a branch of Tilia parvifolia* (Kuy Wandt.).—Plates 16 and 17 represented the stem of dicotyledons in its youngest stage, with separate fibro-vascular bundles. In branches and stems which have a longer duration than one year, the vascular bundles, which at first were isolated, join sideways, so as to form a continuous ring of wood and outside a continuous ring of bark, with a cambium layer between wood and bark. The parenchyma,

by which the isolated fibro-vascular bundles of young shoots were surrounded, is, in this stage, represented by the pith, the medullary rays, and the outer bark layers.

The elements of which wood and bark of the Lime tree are composed are represented (mostly) on plate 9. They are formed out of the cambium cells.

19. *Transverse and radial section through a branch of Cytisus Laburnum.*—This plate clearly exhibits the different elements of wood and bark. *Note* the arrangement of ducts in groups and the sclerotic cells in the bark.

20. *Juniperus communis; wood, transverse radial and tangential section.*—The wood of conifers consists only of medullary rays and tracheids; the latter have the well-known and remarkable bordered pits. In the spring wood, the tracheids are wider and have thinner walls than in the autumn wood. The bordered pits are always on the radial face; only the narrow thick-walled tracheids, formed in autumn, have them sometimes on the tangential face (De Bary's Anatomy, English translation, page 495; Robert Hartig, Das Holz der Deutschen Nadelwaldbäume, 1885, page 13).

21. *Polypodium vulgare; transverse section of stipes* (Kuy Wandt.).—On both sides of the xylem portion, which occupies the centre, are sieve tubes and companion cells; this may, therefore, be styled a bicollateral bundle, but concentric bundles are also found in ferns. *Note* the thickened and coloured walls of the innermost layer of the parenchyma, which surrounds the bundle. Also the cells with starch immediately surrounding the xylem portion, as well as in the circumference of the bundle. (Strasburger's Bot. Pract., page 210.)

22. *Rootlet of Rye; transverse section* (Kuy Wandt.).—The central fibro-vascular bundle in this case is radial—that is, the woody fascicles (xylem) and liber fascicles (phloem) are arranged in radial lines. The former consist chiefly of ducts; the latter of sieve tubes. There is, besides, a large central duct with pitted walls. Radial bundles are commonly found in roots. The bundle is surrounded by a sheath of thick-walled cells. *Note* the root hairs on the epidermis, which take up water and mineral salts in solution from the soil.

23. *Development of terminal bud of Euonymus japonicus* (Strasburger's Bot. Pract., page 253).—The lower figure only is highly magnified. *Euonymus* has opposite leaves, the succeeding pairs standing at right angles to each other. The topview shows pairs 1, 2 (with buds in the axils), 3, 4 (with buds). The longitudinal section shows pairs 2, 4, 6, with buds

in their axils. The primary or initial cells of the epidermis are called Dermatogen, those of the bark Periblem, and those of the pith and fibro-vascular bundles Plerome. Between Periblem and Plerome, there is the ring (correctly hollow cylinder) of Procambium cells, which develope into fibro-vascular bundles. At this stage, the cells of plerome and periblem contain large concretions of crystallized calcium oxalate, a substance commonly found wherever the vegetation is active.

24. *Development of rootlet of Rye* (Kuy Wandt.).—For this and plate 22, consult Strasburger's account of the root development of Barley (*Hordeum vulgare*) in "Bot. Pract.," page 269. The end of growing rootlets, which have to force their way into the soil, is protected by a peculiar structure, the root-cap, or calyptra, consisting of parenchyma, the cells of which have only a short duration. The layers of initial cells, where the renewal of the root-cap takes place, are found upon the outside of the rootlet itself, and they are known as calyptrogen. By means of an active process of cell division, the inner layers of the root-cap are constantly *re* formed, while the outer layers are pushed forward, the cells on the surface being gradually thrown off as they are replaced from inside. This is as the process presents itself in Rye and other grasses. In most dicotyledons the initial cells of the cap are confluent with those of the epidermis of the rootlet. But the cambium-like tissue, where the cap is formed and the elongation of the rootlet takes place, is always protected by the cap in rootlets which must penetrate the earth.

The tissue of the growing end of the rootlet itself has, at this stage, a homogeneous appearance, and resembles the initial tissue of the terminal bud (plate 23); but the difference between the different portions of the tissue is more marked, and of course the final structure of the rootlet is different. All cells of this tissue, as well as those of the cap, are filled with protoplasm and have a nucleus. The epidermis has a thickened outer wall, intercellular spaces filled with air are formed in the periblem, and the vertical line of cells which developes into the large central duct are clearly visible. The technical terms which are commonly accepted for the different concentric layers in the growing point of the rootlet are:—I. Epidermis, Dermatogen, Periblem, Endodermis, all of which form the bark, and, in the present instance, originate in a few initial cells at the top, which are common to these tissues; II. Plerome, which developes into the central fibro-vascular cylinder.

## *IV.—Leaf.*

25. *Leaf of dicotyledons; Beech* (Strasburger's Bot. Pract., page 227).—Chlorophyll is abundant in the parts exposed to the light of most plants with independent existence. Some parasites—such as *Viscum, Loranthus*—also have chlorophyll; in others—*Orobanche* and the beautiful purple-flowered Indian *Æginetia*—it is wanting. In phænogamous and many cryptogamous plants, chlorophyll is an essential constituent of the assimilative cells, and, as far as we know at present, chlorophyll granules, under the influence of light, decompose carbonic acid and water, and form carbo-hydrates and other organic substances. In a few cases, chlorophyll occurs in parts not exposed to the light—for instance, in the inner layers of the bark and in the embryo of some seeds. These, however, are exceptional cases, the physiological meaning of which is perhaps not yet fully understood. As a rule, chlorophyll is abundant in cells in which the process of assimilation takes place under the influence of the light. Plate 18 represents chlorophyll in the bark, and plates 3, 12, 13, 25, 26 in leaves (3 of a water plant). By means of solvents, the green pigment can be removed, and what remains consists of protoplasm, in which are often embedded starch granules.

In the leaf of the Beech, represented on plate 25, chlorophyll is found in four descriptions of cells: (1) in the guard cells, whereas it is wanting in the other cells of the epidermis; (2) in the palisade cells, which stand at right angles to the upper epidermis—here the chlorophyll grains are generally on edge, at right angles to the epidermis, and attached to the narrower side walls of these cells; (3) in the cells of the spongy parenchyma, which occupies the lower half of the leaf, and are separated by large intercellular spaces. *Note* the peculiar arrangement of several palisade cells joining on to one cell of the spongy parenchyma; (4) in the cells surrounding the fibro-vascular bundle.

This peculiar arrangement is suggestive, although we are not yet able to understand its meaning completely. Through the fibro-vascular bundle the water, with salts in solution, which the roots take up, is conducted through the stem into the leaves. Carbonic acid enters through the stomata into the intercellular spaces, and, under the influence of light, protoplasm, starch, cellulose, and other organic substances are formed through the action of chlorophyll. Among others, calcium oxalate is formed, the crystals of which are found in some of the cells near the fibro-vascular bundle.

The fibro-vascular bundles also have the duty of carrying away into the stem and roots a portion of the organic substances elaborated in the leaves. So that there is a continued interchange of substances in the elements of which the leaf consists. At night a portion of the organic substances in the leaf is decomposed and carbonic acid is exhaled, for which purpose oxygen is taken up. Corresponding to the arrangement of its tissues in the stem, the wood portion of the fibro-vascular bundle is near the upperside and the liber portion near the underside of the leaf. On the outside of the wood portion, there are thick-walled elongated cells known as collenchyma. The walls of collenchyma cells swell greatly upon the application of dilute acid, a diluted solution of caustic potash, and even of water. Regarding collenchyma cells, see Sachs' Vorlesungen, page 169; Dé Bary's Anatomie (English Translation), pages 119, 538.

26. *Leaf of Pinus Laricio* (Kuy Wandt.).—The picture represents one edge of the needle only. The centre part of the leaf is occupied by parenchyma without chlorophyll, which surrounds the fibro-vascular bundles, and is enclosed within a sheath or endodermis. The rest of the needle consists of parenchyma cells containing chlorophyll, the walls of which are folded in a peculiar manner. Here, as in the palisade cells of the Beech, many of the chlorophyll grains are attached to the walls of the cells, and the folds mentioned may possibly be of importance physiologically, as increasing the surface of the walls. Enclosed in this green parenchyma are resinous ducts, surrounded by a layer of thin-walled cells and an outer layer of thick-walled fibres.

The epidermis consists of cells, the cavity of which is almost entirely filled up by the thickening of the walls. At the edges of the leaf the epidermis cells are larger, and this is even more so the case in other species (*Pinus Pinaster*, Sachs' Vorlesungen, page 169). The stomata, which in *Thymus Serpyllum* and *Fagus sylvatica* (plates 12, 25) are on a level with the epidermis, are sunk in this instance. Below the epidermis are one or several layers of thick-walled elongated cells and fibres, the fibres being generally at the edges of the leaf. This is generally called the hypoderm (see Strasburger's Bot. Pract., p. 233).

## *V.—Ovule.*

27. *Development of Ovule previous to fertilization* (Kuy Wandt.).—This plate shows the successive growth of an

anatropous ovule, with two integuments, and the formation of the embryonal sac (see Strasburger's Bot. Pract., page 521).

28. *Fertilization of Ovule of Viola tricolor.*—Surrounded by the two integuments, except at the apex, where an opening is left, called micropyle, is an ovoid mass of tissue, called the *nucellus.* (From plate 8, it will be remembered that the *cell-nucleus* often encloses one or several *nucleoli.* The nucellus, it should be remembered, has nothing to do with the nucleolus, but is a tissue composed of numerous cells.) A large cell, the embryo sac, is enclosed in the nucellus. When the pollen grain has been deposited upon the stigma, it swells, and a tube is thrust forth and grows through the loose tissue of the style into the ovary, finding its way, in a manner not yet fully explained, to the foramen and to the embryo sac. At that time, the protoplasm of the embryo sac has generally formed three separate masses (cells without a wall) near the apex, and the same number at the opposite end of the embryo sac. One of the three cells at the apex is called the ovule cell, or oösphere, the two others the synergidæ; the three cells at the bottom are called the antipodal cells.

Part of the protoplasmatic contents of the pollen tube seems to pass over into one of the synergidæ, upon which the oösphere, or ovule cell, increases in size, and eventually, by means of repeated cell divisions, grows into the embryo. In some plants, the embryo fills the seed within the integuments, replacing the nucellus entirely (pea, bean); in others, as in *Viola,* wheat, castor-oil, endosperm is formed, and this takes place by means of the formation of new cells in a portion of the embryo sac. The plate does not clearly represent this part of the process. Strasburger's Bot. Pract. page 524, and Sachs' Vorlesungen, page 931, should be referred to.

The essential point is that some of the substance of the plant, which formed the anther and the pollen grain, is communicated to the ovule, and that the seed is thus the result of the coöperation of two plants, or, in the comparatively rare cases of self-fertilisers, of pollen and ovule of the same plant.

These remarks relate to angiosperms only. In coniferous trees (gymnosperms), the general features are the same; but there are important differences in detail. Regarding this subject, reference should be made to Strasburger's "Bot. Pract.," page 475.

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